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# DEPARTMENT OF DEFENCE

## DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

## AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aircraft Materials Technical Memorandum 397

# INTERIM REPORT ON ENVIRONMENTAL PROGRAM - DURABILITY OF GRAPHITE/EPOXY HONEYCOMB SPECIMENS WITH REPRESENTATIVE DAMAGE AND REPAIRS

by

P.D. Chalkley and R.J. Chester

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**SUMMARY**

An experimental trial is underway to determine the effect of tropical exposure, cyclic loading and thermal cycling on the long term durability of damaged graphite epoxy laminates. No damage growth has been observed after 300,000 cycles at a strain level of 2500 microstrain.

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## 1. INTRODUCTION

The introduction of F/A-18 aircraft into RAAF service has brought a new era of materials technology to Australia; for example the F/A-18 incorporates significant quantities of graphite/epoxy (Gr/Ep) composite materials which form 34% of the external surface area of the aircraft. Major components constructed from Gr/Ep are the main wing skins, trailing edge flaps, vertical tail skins, horizontal stabilators, speed brake and access doors. The main wing and vertical tail skins are thick laminates (up to 23mm) used in a monolithic form (bolted to underlying aluminium alloy substructure), while the other composite components employ a sandwich form of construction in which thin laminates (2 to 30 plies) are adhesively bonded to an aluminium honeycomb core.

The use of Gr/Ep in the above areas offers numerous advantages over a conventional metallic structure; these include increased stiffness, reduced weight, resistance to corrosion and resistance to tension-dominated fatigue loading. Perhaps the major in-service disadvantage of Gr/Ep is its susceptibility to damage from low energy impacts. Impacts such as dropped tools, large hailstones, runway stones, bird strike or accidental hard contact with ground service equipment which may cause no significant damage to an aluminium skin, can cause delamination, matrix cracks and fibre fractures in a Gr/Ep skin. The aircraft components which have a sandwich form of construction are particularly susceptible to this form of damage due to the relatively thin laminates used. The residual tensile strength following such damage is not usually significantly reduced. However, reductions in residual compressive strength of 30% are commonly reported. Because of conservative design procedures, reductions of this magnitude are unlikely to reduce the residual strength of a component to critical levels. However, there is concern that such damage may grow in size under cyclic compressive loading and may ultimately cause a reduction in strength to below acceptable levels.

Although Gr/Ep composite materials are immune to corrosion, they are susceptible to environmental degradation from both ultraviolet radiation and moisture absorption. Ultraviolet radiation has the effect of breaking the molecular cross-links in the matrix epoxy resin exposed at the surface with the result that these weakened surface layers are then lost by erosion. Although conventional paint schemes prevent the loss of the surface layers, it is possible that ultraviolet degradation of the surface layers of the laminate may still occur if radiation penetrates the paint. Such degradation could result in reduced compressive strength if the matrix is unable to provide sufficient restraint to the surface fibres to prevent buckling. Moisture absorption is a well known characteristic of epoxy resins and has the effect of lowering the glass transition temperature (Tg). The value of Tg marks the transition from a glassy to a rubbery state and as such denotes the temperature at which a drastic reduction in the compressive properties of the laminate occurs. For a moisture absorption level of one percent by weight of the composite (or approximately three per cent by weight of the resin) Tg would be typically reduced from 175$^{o}$C to 130$^{o}$C. It is possible, therefore, that large amounts of absorbed moisture could plasticize the matrix sufficiently to affect the compressive properties in general and delamination propagation properties in particular.

This report, on work performed as part of a RAAF sponsored ARL task (Dr A.A. Baker - Task Manager), details an experimental program set up to investigate the effect of representative environments on delamination growth in-

Gr/Ep structures representative of the F/A-18. The task is entitled 'F/A-18 Composites; Environmental Durability', Number 86/044. Other sections of this task include:

- estimation of moisture absorption in F/A-18 type Gr/Ep laminates subjected to various environmental conditions,

- environmental durability of F/A-18 type Gr/Ep bonded joints (Double Overlap Fatigue specimens representing repairs),

- environmental durability of F/A-18 type Gr/Ep-Titanium, adhesively bonded joints, and

- environmental durability of F/A-18 type Gr/Ep-Aluminium alloy bolted joints.

These other sections will be the subject of separate reports.

The data obtained from this task will provide information on the likely durability and damage tolerance of a range of structural details of relevance to the F/A-18 aircraft, as well as an indication of moisture absorption levels, durability of repairs and degradation of paint schemes.

This task involves use of the Joint Tropical Trials and Research Establishment (JTTRE)* at Innisfail, North Queensland as well as laboratory facilities at ARL. Specimens are continually exposed to tropical conditions involving high levels of humidity, temperature, UV radiation and wind at the tropical site, which are very difficult to reproduce in a laboratory; the laboratory tests are mainly employed for comparison purposes. The test specimens in the honeycomb sandwich beam program are carefully prepared so as to accurately represent thin skin structure typical of that found on the F/A-18. In addition to the tropical environment, the specimens are exposed to several other significant conditions which the aircraft experience during service:

- compressive fatigue loading

- compressive overloads after each block of fatigue loading

- thermal cycling between +105$^{o}$C (supersonic dash) and -50$^{o}$C (low speed flight at high altitude).

During the trial, the specimens are periodically examined by strain measurements and ultrasonic C-scans in order to detect delamination growth. As well as providing data during the trial on durability and damage growth rates, the specimens will be tested to failure at the end of the trial to obtain the residual compressive strength which is an indication of their damage tolerance. Information such as this should aid the RAAF in providing through-life-support for the F/A-18 aircraft by allowing appropriate inspection intervals to be set, and by defining damage sizes below which repair is not required..

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* Now MRL Queensland

## 2. TEST SPECIMENS

### 2.1 Construction and Test Approach

The design of specimens for compression testing must ensure that specimen buckling does not occur prior to compressive failure. Thin laminates, which are the object of this program, are especially prone to buckling, however, they can be readily stabilised by incorporation into a honeycomb sandwich beam. Such beams are commonly loaded in four point bending in which a uniform uniaxial plane stress state is developed, without through-thickness shear stresses between the two central load points. This method of load introduction for compression testing is comparatively simple compared with that used for uniaxial tests, and is particularly attractive for long term testing where periodic specimen removal is required, as no particular attention to gripping or specimen alignment is needed.

The specimen chosen for this trial, shown schematically in Fig. 1, consists of two Gr/Ep laminate skins bonded to an aluminium honeycomb core. The skins are made from Hercules AS4/3501-6 pre-preg, the material used on the F/A-18; ply construction is (a ten ply) $([\pm45/0/90/0]_S)$, similar to the construction of the F/A-18 speed brake. The autoclave cure cycle consisted of a) vacuum to remove air, b) apply 586 kPa to outside of bag, c) heat to 116°C in 45 minutes and hold for 1 hour, d) vent vacuum and increase pressure to 680 kPa, and e) heat to 175°C in 45 minutes and hold for 2 hours. Panels were then post-cured at 175°C for 4 hours. Most of the skins for this program were manufactured under contract by Hawker de Havilland, Australia.

The honeycomb core material was Hexcel CR111/1/8/5052/0.003, 25mm thick. This is a 1/8 (3.2mm) inch cell honeycomb made from 5052 aluminium alloy foil 0.7mm thick with a corrosion-resistant coating. A heavy core (192 $kg/m^3$) was chosen to avoid compression or shear failure in the core or shear failure in the adhesive layer. Some beams were prepared with a small central region of lighter gauge core (72 $kg/m^3$) joined to the outer heavier sections with a foaming core splice adhesive, FM 404. This configuration was employed to maintain the required compressive strength under the loading rollers while still providing realistic restraint for the central impact region as detailed in the next section. The skins were bonded to the honeycomb core with FM-300 structural film adhesive.

### 2.2 Damage Types and Repairs

Five different types of beams were prepared:

- i) Undamaged
- ii) Artificial delamination (teflon inclusion)
- iii) Impact damage (prior to bonding skin to core)
- iv) Impact damage (after bonding skin to core)
- v) Simulated repair.

a) Damaged Beams

The artificial delaminations were produced by inserting two layers of PTFE film between the second and third plies of the skin during lay-up. These inclusions were punched from 0.0254mm thick film in the shape of round discs and had diameters of 5, 15 and 25mm. The impact damage was produced using a drop

weight impactor with a one inch diameter spherical steel head weighing 506 g. A threshold energy level of 0.3 Joules was observed, below which apparently no impact damage occurred. Above this energy level the extent of damage increased with impact energy as shown in Fig. 2. The skins impacted prior to bonding to the core, were attached to aluminium honeycomb (Hexcel CR111/1/8/5052/.001 - 72 kg/m$^3$) with double-sided adhesive tape during the impacting. This light-gauge core is representative of that used in the speed brake and horizontal stabilator and other areas involving light-weight sandwich panels in the F/A-18. These specimens contain realistic impact damage in the skins without any crushed core or debonds between skin and core. The specimens impacted after bonding to the core have central spliced-in sections of the light gauge core onto which the impacts are directed. This ensures that the level of damage is similar to the other impacted specimens, and also allows investigation of the effect of crushed core and skin to core debonds on damage behaviour. Details of the actual damage sizes are given in Table 1.

b) Repaired Beams

As well as the undamaged and damaged beams described above, some specimens were produced with representative repairs in order to determine the durability of such repairs under long-term environmental exposure. The geometry of the repaired beam specimens is shown in Fig. 3. For easier interpretation of results, an external patch is bonded to each side of the beam so that the specimens are stiffness-balanced about their center plane. Each specimen then provides data on the effect of both compression and tension loads. The repairs are based on either precured or cocured patches bonded to the parent laminate with FM-300K adhesive. The following repair conditions are being investigated:

i) a baseline condition in which precured patches will be bonded under autoclave conditions to a dry (unmoisturised) sandwich-beam specimen,

ii) a precured patch bonded under optimum vacuum bag conditions to a partially dried sandwich-beam specimen,

iii) a cocured patch bonded under optimum vacuum bag conditions to a partially dried sandwich-beam specimen.

Cure pressures were 103 kPa for both the vacuum bag procedure (which is representative of the pressure which can obtained under actual repair conditions) and for the autoclave procedure (which provides a baseline comparison without the effects of the vacuum). The precured patches were cured using the same conditions given in section 2.1 for the skins, while the cocured patches were given a pre-consolidation treatment. This consisted of debulking under vacuum and then a shortened autoclave cure cycle which involved: a) applying a vacuum under the bag, b) applying an external pressure of 586 kPa, and c) heating to 116$^{\circ}$C in 45 minutes and holding for 60 minutes. This treatment consolidates the patch to approximately the desired final thickness, and removes most of the excess resin while still allowing sufficient conformability of the patch during the final cure to accommodate any surface curvature. The FM 300 K adhesive is cured at 175$^{\circ}$C for one hour after a 45 minute heat-up from room temperature.

The patches have a ply drop-off step of 3mm, and comprise a total of 10 layers. The overlap length is approximately 65mm which is estimated to be adequate for load transfer even when the adhesive is in the hot fully moisturised condition.

Prior to repair, the undamaged sandwich beam specimens, which were bonded using vacuum bag conditions, were moisturised to 1% in a water bath held at 70°C. Following this treatment the skins were dried at 70°C (below 100°C to avoid internal pressure, due to steam formation from any moisture which may have been trapped in the honeycomb, which could debond the skins). This treatment simulates repair conditions in which a component would be dried prior to repair in order to prevent water in the laminate forming voids in the bondline or otherwise interfering with the cure. Coupon specimens, representative of F/A-18 structure, are currently being exposed at bases where aircraft are stationed, in order to provide a data base of moisture absorption by Gr/Ep laminates. These data would be used, for example, to calculate the probable moisture content of an aircraft component so that appropriate drying procedures could be undertaken prior to repair. Details of these moisture absorption trials will be published in a separate report.

Following drying, approximately 1600mm$^2$ of skin is removed from the centre of the beam using a tungsten carbide-tipped router bit. A layer of adhesive is then inserted into the gap and the patch is bonded or cocured over this region with an adhesive film.

### 2.3 Strain Gauges, Sealants, and Paints

Strain gauges have been attached to selected beams in order to measure the stiffness reductions associated with delamination growth or other damage, or patch degradation in the case of the repaired beams. Strain gauges on the damaged beams were located adjacent to the damaged regions but sufficiently far away to allow C-scanning. Selected repaired beams have two gauges, one close to the end of the patch to detect bond failure and the other above the skin/filler interface (Fig. 3) to detect debonding in this region. It was envisaged that the trials would last up to four years and so it was desirable that the strain gauges could survive tropical exposure outdoors for this period of time without maintenance. Several combinations of strain gauges and sealants were evaluated under both tropical conditions and accelerated laboratory ageing conditions, in order to determine their suitability for the trials (Ref. 1). A fuel-resistant polysulphide rubber, Selleys PR-1422, was found to provide good protection to gauges bonded to Gr/Ep laminates when exposed outdoors in tropical conditions for periods of at least 40 months. Other sealants tested were found to de-bond from the surface and expose the gauge to moisture which led to corrosion. The resistance of some gauges was found to increase by seven percent in ten weeks due to corrosion. A change in resistance during loading of 0.4 percent results in an error in indicated strain of 2000 uE (microstrain), so it is obvious that corrosion can be a serious problem.

The strain gauges finally selected were Micro-Measurement WA series gauges (WA-03-125BT-120) which are fully encapsulated to withstand extreme environments and have high endurance leadwires. These gauges are bonded to the beams using M-Bond 43B a single-component, solvent-thinned epoxy, which was cured at 170°C for 2 hours. The beams were then painted with the standard F/A-18 paint scheme which consists of a two-part epoxy polyamide anti-corrosive

primer and a two-part aliphatic polyurethane enamel finishing coat. The finishing coat is applied in two colours; a light grey to the underside of the aircraft and a darker grey to the top surfaces. Only the darker grey was applied to the beam specimens. Following painting, the gauges were wired and then PR-1422 sealant was applied over the gauged area and also around the edges of the beams to protect the aluminium honeycomb from moisture ingress.

## 3. LOAD APPLICATION

The honeycomb sandwich beam specimens are dynamically loaded in hydraulically-actuated load frames as shown in Fig. 4. Each load train of stainless steel links holds twelve specimens, and is fixed at the top to the load cell and loaded at the bottom by an hydraulic ram. This arrangement ensures that equal load is applied to all specimens. Hydraulic actuation was preferred over an electrical motor and mechanical linkages for reasons of lower cost and greater versatility in terms of loading rates and the load levels applied. Corrosion was also considered to be less of a problem in an hydraulic system. In-service experience, however, has now shown that the tropical environment at Innisfail causes rapid corrosion of exposed metallic components, so that it is essential that all components are either stainless steel, galvanized, or covered with a corrosion-protective coating.

A schematic diagram of the hydraulic system used in the loading rigs is shown in Fig. 5a. The maximum load to be applied to the specimens is set by adjusting the pressure relief value (PRV). The directional control valve (DCV) applies hydraulic pressure to the ram for the time interval selected on the control box (ram-on time). When the DCV is switched off, the elastic energy in the beams pulls the ram back to the starting position. Proximity switches were initially used to sense when all the rams had returned to the zero load position, so that the next load cycle did not start prematurely. In practice, however, changes in temperature, and hence hydraulic fluid viscosity, were such that the total cycle time varied to such an extent that the maximum limit set for the total cycle time was occasionally exceeded. It was therefore necessary to replace the proximity switches at JTTRE with timers which control the DCV such that ram on and ram off times of 38 seconds were achieved. The disadvantage of this technique is that not all rigs returned to zero load during the ram off cycle. However, the residual load is likely to be less than five per cent of the maximum and is therefore considered to be insignificant. Control of the loading rates and hold times are achieved via the flow control valves (FCV), Fig. 5a. A saw-tooth loading cycle is desirable from a data acquisition viewpoint, and the FCVs are set to approximate this as closely as possible, Fig. 5b.

The sandwich-beam specimens are loaded dynamically at approximately 0.013 Hz for blocks of 100,000 cycles at a load level which produces a strain of -2500 uE in the compression skin. This load is approximately 2600 N and is controlled by the PRV. At the completion of each 100,000 cycle loading block, the beams are removed from the load frames and ultrasonically C-scanned in order to detect damage growth. The beams are then given 20 overload cycles in an Instron load frame at a strain level of -3500 uE in the compression skin. The next step is to thermally cycle the beams by cooling to -50$^{o}$C in a $CO_2$ bath and then heating them to 105$^{o}$C in an air circulating oven. During this procedure, thermocouples are attached to the skins of the beams, which are then wrapped in aluminium foil to minimise moisture loss. This thermal cycle is repeated five times, after which another 20 overload cycles at -3500 uE are applied. Before the

beams are returned to the rigs for another loading block, they are C-scanned again to check for damage growth resulting from the overload or thermal cycles.

An unexpected problem was encountered during the first loading block in that the beams were observed to be lying at a small angle to the horizontal when viewed from the end. This problem was caused by the beams moving laterally across the loading rollers so as to assume a minimum energy position against one side of the load train links. As a result of the movement the teflon loading rollers became deformed preferentially on one side, thus exacerbating the degree of tilt. To minimise this problem graphite impregnated nylon rollers (which do not deform as easily as the teflon) were fitted, together with packing washers to prevent lateral movement of the beams across the rollers. The aim is to restrict the beams to the centre of the load train where they lie in the correct position, perpendicular to the loading axis.

## 4. ENVIRONMENTAL EXPOSURE

The testing site, J.T.T.R.E. at Innisfail, is situated within the tropics at latitude 17$^{\circ}$ south (Tropic of Capricorn is at 23$^{\circ}$ South). Proximity to a mountain range reaching 1500m ensures conditions of high humidity all year round. The average daily mean relative humidity is over 80%, as shown in table 2, U.V. radiation is an intense 64 KWh/m$^2$. Average data for Melbourne included in table 2, shows that major differences include lower temperatures, and significantly lower rain fall and humidity in Melbourne.

The paint on the beams, the same as that applied to the top of the F/A-18 wings, provides a barrier against the ingress of water and a major barrier to damage to the matrix by ultraviolet light but is not totally impervious to water nor possibly to ultraviolet light. To study any effect of U-V light on damage growth and development, there are an equal number of beams with their compression skin facing up as facing down.

Exposed concurrently with the beams are witness and companion coupons. There are six companion and six witness coupons for each loading rig. The coupons have a $[\pm45,0,90,0]_{S2}$ layup and dimensions of 105 x 45mm. The thickness of the coupons is twice that of the beam skins as moisture can only penetrate the skins from one side. The coupons are held in a jig attached to the loading rigs. Three witness and three companion coupons have a face exposed to the sunlight. The other six are in shade. This system models the two types of exposure the beams receive, i.e. compression skin up and compression skin down. Both types of coupons are removed from the jigs on the load frame when the beams are removed. The companion coupons accompany the beams during thermal cycling while the witness coupons experience, as closely as possible, the same exposure as the beams except for the thermal cycling. Therefore, any damage that occurs due to thermal cycling, such as interlaminar cracking, should be reflected in an increase in the moisture level of the companion coupons over that of the witness coupons.

By weighing the coupons, both witness and companion, before each lot of thermal cycling, the effect of environmental exposure, both with and without thermal cycling, on moisture content of the gr/ep skins can be monitored.

## 5. EVALUATION OF DAMAGE GROWTH

Three methods are being used to measure the growth of damage in the sandwich beam specimens; compliance changes, ultrasonic C-scanning, and residual strength measurements. These will be discussed in turn.

### 5.1 Compliance Change

Although an increase in compliance of a beam does not provide an absolute measure of damage growth, it provides an indication that growth has occurred. If a significant change in compliance occurs, that beam can be removed from the loading rigs and C-scanned in order to measure the extent of the damage growth. The compliance of the beams is monitored by means of the strain gauges bonded to the skins. The longitudinal coefficient of thermal expansion of the beams was calculated to be $3 \times 10^{-6} C^{-1}$ and hence strain gauges which were self-temperature compensated for this value were selected in order to minimise temperature-induced apparent strain. Three-wire quarter-bridge circuits were used for the same reason, as accurate strain readings are required during the final residual strength measurements (Section 5.3).

Despite the trials carried out to choose a strain gauge/sealant combination which will prevent corrosion of the gauge, it is likely that corrosion will occur to some extent and hence that the gauge resistance will increase. The data reduction technique is to calculate the strain from the equation.

$$e = \frac{-4Vr}{GF\ (1+2Vr)} \qquad (1)$$

where GF is the gauge factor and Vr is given by

$$Vr = \left(\frac{V\ output}{V\ excitation\ loaded}\right) - \left(\frac{V\ output}{V\ excitation\ unloaded}\right) . \qquad (2)$$

The output and excitation voltages of the bridge are determined by direct measurement of the bridge resistances,

$$\frac{V\ output}{V\ excitation} = \frac{R_3}{R_3 + R_g} - \frac{R_2}{R_1 + R_2}$$

where $R_g$ is the strain gauge resistance, $R_3$ the completion resistor (= 120 ohms) and $R_1$ and $R_2$ the other half bridge (= 500 ohms each).

The unloaded voltage ratio is measured at the start of each loading block and this value is then subtracted from the values taken during cyclic loading. This unloaded voltage ratio involves the measurement of gauge resistance at a particular time. The subsequent readings of the loaded voltage ratio will differ due to a) the applied strain on the gauge, b) temperature differences, and c) corrosion of the gauge. If measurements of the loaded ratio are taken at a different temperature to the unloaded ratio, they will contain an apparent strain component due to the mismatch in thermal expansion coefficients of gauge and skin; however, this is not important. Such apparent thermal strain will increase or decrease the individual strain readings (depending on the

temperature difference). However, as long as the temperature of the gauge and skin does not change significantly during the time (approx 30 seconds) it takes to record data from a complete loading cycle, the compliance calculated from the data will be unaffected, Fig. 6. Note that the sign of the apparent strain depends upon the type of alloy used in the strain gauge. Type A alloys display negative apparent strains for temperatures from cryogenic to 180°C (assuming an application temperature of 24°C), Ref. 3. Corrosion of the strain gauge will have a similar effect in that, although any individual strain reading will no longer represent the true strain on the specimen, the compliance calculated from a set of load-strain data pairs will be unaffected. The compliance will be affected by any non-linearity introduced into gauge output with respect to load. Tests are being conducted to determine if severe corrosion is likely to cause the gauge to become non-linear. At the beginning of each loading block of 100,000 cycles, a new unloaded voltage ratio is taken which essentially re-positions the start of the stress-strain curve to the origin.

The strain gauges and load cells are connected to a Hewlett Packard 3497A Data Acquisition unit which is housed in an air-conditioned laboratory some 15 metres from the loading frames. During the loading (ram-on) cycle, measurements are taken of the load cell and strain gauges and the beam bending compliance is calculated. Approximately ten load/strain readings can be taken from each of 40 strain gauges during a single loading cycle. This is repeated three times and the three values of modulus obtained are averaged and compared with the baseline values obtained prior to exposure. Because the compliance of the beams is expected to vary with temperature and moisture content, it was decided to ignore compliance changes of up to 5%. Compliance data collected from the beams are relayed to ARL via a Digital Data Link.

The digital data network offered by Telecom has been used to transfer data from J.T.T.R.E. to the Materials Research Laboratories (MRL) in Melbourne. Access to the data link has been achieved by connection of the necessary modems to the Microvax at JTTRE and the Vax at MRL. Information is relayed by use of microwave and radio transmitters and receivers and the probability of loss of data is extremely small. Data transfer between the Vax at MRL and the ELXSI at ARL is achieved using the program Kermit. Overall, this system provides a much more reliable method of data transmission than the standard phone lines.

### 5.2 Non-Destructive Inspection

Ultrasonic C-scanning was selected early in this program as the primary NDI technique for the measurement of damage growth. A commercial ultrasonic thickness-measuring instrument, the Novascope 2000, was selected as the basis of the system, as the filtering facility in this instrument was found to produce good results with Gr/Ep materials which can have a noisy ultrasonic signature. This instrument is basically a hand-held thickness-measuring device, and in order to automate the scanning process, an X-Y scanning frame and microprocessor control unit were developed. During scanning the beams are immersed in a water tank beneath the scanning frame, and the probe is scanned over the damaged regions according to the scan limits and speed, which are entered into the microprocessor.

The Novascope outputs digital and analog voltages which represent the distance from the front surface of the laminate to the first detectable reflection of ultrasound. In the absence of any damage the first reflection will be the back surface. This voltage is transmitted to the microprocessor where it is compared

with previously set threshold levels representing the front and back surfaces of the laminate. If the voltage is found to be between these threshold values, it will have arisen from internal damage in the composite and the microprocessor accordingly lifts the plotter pen so as to record the presence of the damage. Full details of this system can be found in Ref. 2. This system differs from the conventional ultrasonic C-scanning method in which the amplitude of the back surface echo is monitored and the plotter responds to variations in the amplitude caused by the attenuative influence of delaminations or other forms of damage.

The beams are scanned immediately after withdrawal from the loading rigs and again after the thermal cycling, before they are repositioned in the rigs. Stainless steel standards with flat-bottomed holes are used to ensure reproducible results for the duration of the trial.

### 5.3 Residual Strength Measurements

The beams will be loaded to failure at the end of the cyclic loading trials, to determine the static failure loads and strains. Results for beams with artifical and impact damage will provide a measure of the damage tolerance of the specimens.

## 6. PRELIMINARY RESULTS

a) Tropical Exposure results

i) Compliance data

The experimental results to date are shown in Figs 7-14. One gauge has failed in service, as shown in Fig. 13. However, the protection system detailed in section 2.3 is providing good protection to the rest of the gauges. The major result is that no consistent compliance changes have occurred at this stage of the program. One notable feature of the compliance results, however, is the large change in compliance which is often visible after the first reading of a new load cycling block, i.e. these changes are visible at 100,000 and 200,000 cycles. These changes are not consistent, in that some beams experience an increase in compliance, some a decrease and others no change. There appears to be no correlation between these changes and whether the compression sides of the beams are facing up or down. Another feature, which is readily visible in Figs. 9 and 10, is that it is quite common for **all** the beams to display a peak or trough in the compliance value, at the same number of cycles. These changes are quite small and therefore insignificant and could arise from either; a) genuine compliance changes in the beams as influenced by the prevailing environment (temperature, moisture content etc), or b) variable friction effects in the load-train. The latter could arise from oxide or dirt build-up in the linkages and could be alleviated by the presence of water on the rigs following rain, or after strong winds during which the linkages are flexed and the friction is relieved. This type of effect may be the explanation for the larger compliance changes experienced after the beams are re-installed in the rigs. In some instances the beams may have been in a position in which friction of some type resulted in a low apparent compliance. After re-installation, the beam may not be influenced by the same friction and hence the compliance suddenly increases. The load-train manipulation during beam withdrawal and installation, combined with the new seating position experienced by each beam after installation, could result in an apparent compliance increase, decrease or no change depending on the individual

circumstances. Interpretation of the compliance data is complicated by these sudden variations, and it is envisaged that it will be necessary to wait for longer times before consistent changes in compliance can be identified.

ii) Ultrasonic C-scans

The C-scan results to date do not show any general increase in damage size; this lack of damage growth is not surprising at this comparatively early stage of the program. As the beams are scanned before and after thermal cycling, it will be possible to distinguish between the thermal cycling and the load cycling as causes of damage growth and to measure the relative importance of each. Typical C-scans of the damaged beams are shown in Fig. 15.

iii) Companion/Witness Coupon Moisture Absorption

The general trend of the companion and witness data is shown in Fig. 16, where percentage mass increase is shown plotted against number of cycles. All specimens have shown an increase in mass with time, with small decreases experienced during the thermal cycling periods when the specimens are inside airconditioned buildings. It is expected that, at longer exposure times, the companion specimens will show a greater degree of moisture absorption than the witness specimens due to damage incurred during the thermal cycling. However, the current results do not always show this trend. Early results from another more extensive moisture absorption program, currently underway, have shown that the initial results may not be indicative of the final behaviour, and it may be necessary to wait for at least twelve months in order to understand the moisture absorption behaviour of the coupons and therefore the skins of the beams.

b) Laboratory Results

Twelve beams have been subjected to two blocks of 100,000 cycles to date at a load producing ~2500 uE in the compression skin. These beams are comprised of six having teflon implants, three having impact damage before bonding to the core, and three having impact damage after bonding to the core. The beams have also experienced two sets of overload and thermal cycles.

i) Compliance Data

A typical plot of load versus strain is shown in Figure 17. No change in compliance of the beams during cycling has occurred.

ii) C-scanning at ARL is carried out using a Novascope 2000 instrument with a Meccasonics X-Y scanning frame and controller. An LSI 11 computer and IBM PC with colour graphics facility, is used to drive the probe and collect data using software developed at ARL. The specimen configuration (honeycomb sandwich beam) requires that careful attention be paid to parameters such as probe normalization, specimen-to-probe distance and instrument settings. The interface from which ultrasound is reflected in the specimen is between the gr/ep skin and the aluminium honeycomb and is associated with the fillet adhesive. This interface has a lower change in acoustic impedance than between a gr/ep laminate and perspex, for example. Hence, noise in the signal can be of the order of the height of the back-surface echo. Ultrasonic C-scans of beams have shown no increase in delamination size to date.

iii) Visible/Audible Indications

During the loading cycle, distinct clicking noises are produced by the beams and visual inspection reveals that those containing the largest teflon implants experience localized buckling of the compression skin in the region immediately above the implant. This out-of-plane movement of the outer plies could result in delamination propagation over time. The noise was first noticed at the beginning of the trial.

iv) Residual Strength Measurements

Residual strength measurements have been made in order to establish a baseline for any deterioration in strength due to long term cycling. Three beams were loaded to failure in four-point bending in a screw-driven Instron. The first contained a 15mm teflon implant between the second and third ply in the compression skin. It failed at a load of 11,730 N and strain of 13,500 uE. Failure, however, occurred at the outer loading rollers where a stress concentration exists. In subsequent tests thin silicone rubber pads with a covering of aluminium were used to reduce the stress concentration at these points. Failure then occurred in the centre of the beam if a teflon inclusion was present.

The second beam tested was in the undamaged condition and failed at a load of 12,150 N. Initial failure occurred in the compression skin close to one of the rollers, and consisted of multiple delaminations spreading away from the roller towards the centre of the beam. Significant among these delaminations were firstly, separation of the top nine plies from the bottom $45^{o}$ ply (no skin to core disbond occurred), and secondly, delamination along the $0^{o}/90^{o}$ interface with the top six plies buckling outwards. Final failure occurred by fibre breakage, both opposite these delaminations in the tension skin,and also close to the other central loading roller in the compression skin.

The third beam tested contained a 25mm teflon implant and a failure load of 10,920 N was recorded. Examination of the failed beam revealed that only the two plies above the implant buckled outwards and that, compared with the second beam, the buckled region was smaller in area and the displacement of the plies from the initial surface was greater. The seven plies beneath the inclusion delaminated from the bottom $45^{o}$ ply in a similar manner to the second beam. However, final catastrophic failure in this case was by fibre breakage in those seven plies.

## 7. SUMMARY

A major experimental trial has been set up to study the durability and damage tolerance of Gr/Ep materials representative of those used in the F/A-18 aircraft. The trial involves both long-term tropical exposure conditions and accelerated laboratory testing which serves to provide a baseline condition. The test specimens are Gr/Ep-Honeycomb sandwich beams which are either undamaged or have been subjected to one of three different types of damage or a simulated repair to the skin.

For the tropical trial the beams are sited outdoors in loading rigs which apply constant amplitude cyclic loads equivalent to a compressive strain of -2500 uE. After each 100,000 cycles of loading, the beams are removed from the rigs and: a) given 40 overload cycles (-3500 uE), b) five thermal cycles from $-40^{o}C$ to

+105°C, and c) subjected to Ultrasonic C-scanning to monitor damage growth. The compliance of selected beams is monitored during load application as a separate measure of damage growth. Moisture absorption experiments running concurrently with the main trials, provide data on changes in the moisture content of the Gr/Ep laminates over time.

At October 1987, the beams subjected to tropical exposure had experienced 200,000-300,000 cycles, while the laboratory beams had undergone 300,000 cycles. No significant delamination growth has been detected at this stage of the trial.

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The authors wish to acknowledge the substantial contributions which a number of people have made to this program over a number of years. These include Dr A.A. Baker, Mr J.D. Roberts and Mr W.R. Broughton from the Aircraft Materials Division, Aeronautical Research Laboratories, the design and development staff from the Engineering Facilities Division, ARL including Mr D. Miller, Mr J. Lowes and Mr G. Fisk, and Mr E.J. Hill, Mr S. Young, Mr E. Shum and Mr I. Williams from J.T.T.R.E.

## REFERENCES

1. Chester, R.J. "A Comparison of Sealants for protecting Strain Gauges during Tropical Exposure". Experimental Techniques, Vol. 11, 1987 p.22.

2. W.R. Broughton and R.J. Chester, "The development of a portable Ultrasonic Facility for NDI of Graphite/Epoxy Composites". J. Australian Inst. for NDT. Vol. 23 No. 2, 1986 p.38.

3. Micro Measurements Technical Note 504 "Strain Gauge Temperature Effects", 1983. Measurements Group Inc.

## TABLE 1

## DEFECT SIZE AND CODE FOR HONEYCOMB SANDWICH BEAMS

## JTTRE RIGS

| Rig No.1 A1 | | Rig No.2 A2 | | Rig No.3 A3 | | Rig No.4 B1 | |
|---|---|---|---|---|---|---|---|
| Beam No. | Defect* size | Beam No. | Defect size | Beam No. | Defect size | Beam No. | Defect size |
| I | - | TDF25.4 | 25 | TDF15.4 | 15 | TD+ 2 | 0 |
| G | - | TDF15.2 | 15 | TUF25.1 | 25 | TUC 0 | 0 |
| TDC15/2 | - | TDF 5.4 | 5 | TDF15.3 | 15 | TD 1 | 0 |
| TDC8/3 | - | TUF 5.2 | 5 | TUF25.4 | 25 | TU 1 | 0 |
| TUC10/3 | 7 | TDF 5.1 | 5 | TDF15.1 | 15 | TDI 13 | 0 |
| TDC10/1 | 12 | TUF 5.1 | 5 | TUF25.2 | 25 | TUC 9 | 11 |
| TUC15/3 | 20 | TDF 5.2 | 5 | TDF15.2 | 15 | TDI 11 | 13 |
| TDC10/3 | 11 | TUF15.3 | 15 | TUF25.3 | 25 | TUI 9 | 10 |
| TUC10/2 | 10 | TDF 5.3 | 5 | TDF25.1 | 25 | TDC 3 | 8 |
| TUC15/2 | 15 | TUF15.1 | 15 | TUF 5.4 | 5 | TUC 8 | 10 |
| E | - | TDF25.3 | 25 | TDF25.2 | 25 | TDC 6 | 13 |
| J | - | TUF 5.3 | 5 | TUF15.4 | 15 | TUC10 | 11 |

| Rig No.5 B2 | | | Rig No.6 B3 | | | Rig No.7 C1 | | |
|---|---|---|---|---|---|---|---|---|
| Beam No | | Defect size | Beam No | | Defect size | Beam No | | Defect size |
| TDC | 0 | 4 | TDI | 14 | 14 | TDC | 20 | 20 |
| TU | 2 | 0 | TUI | 13 | 13 | TUC | 17 | 17 |
| TDI | 11.1 | 13 | TDI | 13 | 13 | TDC | 17 | 17 |
| TUC | 3 | 11 | TUI | 9 | 9 | TUC | 20 | 20 |
| TD | 3 | 0 | TDI | 9 | 9 | TDI | 7 | 7 |
| TUC | 6 | 9 | TUI | 11 | 11 | TUI | 7 | 7 |
| TDC | 3 | 8 | TDI | 12 | 12 | TDI | 8 | 8 |
| TUI | 14 | 14 | TUI | 12 | 12 | TUI | 10 | 10 |
| TD | 4 | 0 | TDI | 12B | 12 | TDI | 9 | 9 |
| TUI | 13 | 13 | TUC | 10 | 10 | TUI | 8 | 8 |
| TDC | 8 | 10 | TDI | 11 | 11 | TDI | 9 | 9 |
| TU | 3 | 0 | TUI | 12.1 | 12 | TUC | 19 | 19 |

CODE:

T: tropical
D: compression skin down
U: compression skin up to sunlight
C: impact after bonding skin to core
I: impact prior to bonding skin to core
F: teflon inclusion

* Defect size is expressed as an equivalent diameter (mm) of a circle of the same area.

\+ No third letter means undamaged.
Beams E, I,G, J are undamaged.

TABLE 1 Continued

Lab A Conditions

Rig 1.

| Beam No | Defect size (mm) |
|---|---|
| AF 25.3 | 25 |
| AI 9 | 9 |
| AI 11 | 11 |
| AC 11 | 11 |
| AC 0 | 0 |
| AC 15 | 15 |
| AI 10 | 10 |
| AF 15.2 | 15 |
| AF 15.1 | 15 |
| AF 25.2 | 25 |
| AF 5.1 | 5 |
| AF 5.4 | 5 |

CODE:

F: Teflon inclusion
A: Lab A

C: impact upon core
I: impact before bonding

| | JTTRE 1987 | Long term average data for Melbourne |
|---|---|---|
| TEMPERATURE (c) | | |
| Highest daily maximum | 37.4 | 40.2 |
| Average daily maximum | 28.5 | 19.9 |
| Average daily mean | 24.1 | |
| Average daily minimum | 21.0 | 10.5 |
| Lowest daily minimum | 12.3 | 1.2 |
| RELATIVE HUMIDITY % | | |
| Highest daily maximum | 100 | |
| Average daily maximum | 96 | |
| Average daily mean | 83 | 68[1] |
| Average daily minimum | 61 | 52[2] |
| Lowest daily minimum | 21 | |
| % of time above 90% RH | 46.6 | |
| % of time above 70% RH | 78.0 | |
| % of time below 60% RH | 10.2 | |
| PRECIPITATION | | |
| Total rainfall (mm) | 2636.0 | 658 |
| Highest daily rainfall (mm) | 199.5 | |
| Number of rain days | 152 | 148 |
| Duration of rainfall (hours) | 365.6 | |
| RADIATION | | |
| Total sun hours | 1782.9 | 2274 |
| Total Global Horizontal ($kWh/m^2$) | 1194.3 | |
| Total UV ($kWh/m^2$) | 64.3 | |

TABLE 2: JOINT TROPICAL TRIALS AND RESEARCH ESTABLISHMENT METEOROLOGICAL SUMMARY FOR 1987 AT THE PIN GIN HILL HOT WET CLEARED SITE.

AVERAGE DATA FOR MELBOURNE IS INCLUDED FOR COMPARISON

1. Humidity at 9am approximates daily mean.
2. Humidity at 3pm approximates daily minimum.

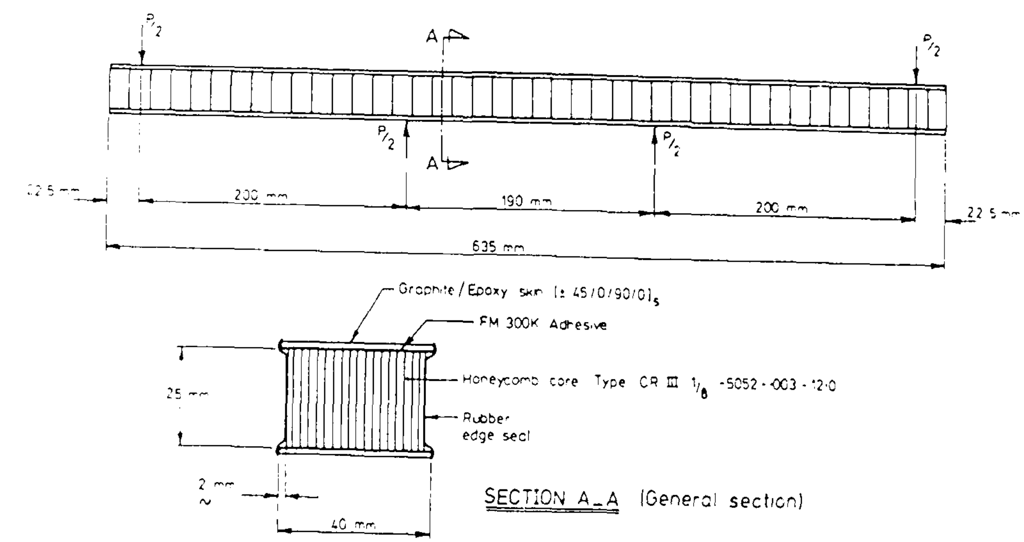



FIGURE 1: SCHEMATIC ILLUSTRATION OF SANDWICH BEAM TEST SPECIMEN, SHOWING LOADING POSITIONS.

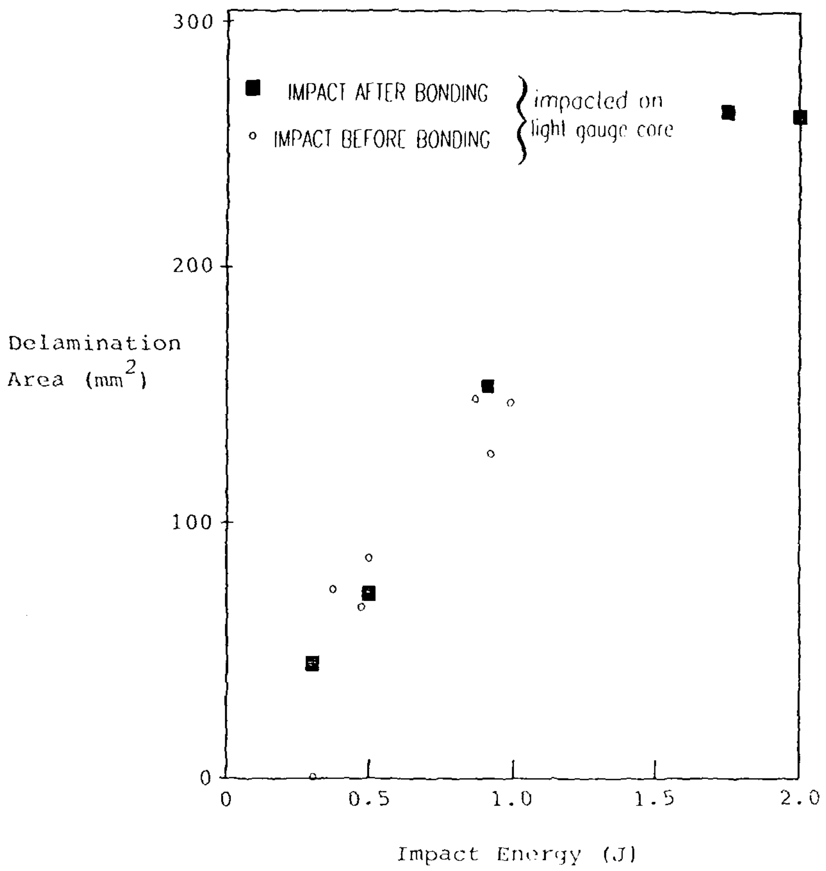



FIGURE 2: VARIATION OF DELAMINATION AREA WITH IMPACT ENERGY (506g IMPACTOR). (DELAMINATION AREA MEASURED WITH NOVASCOPE ULTRASONIC INSTRUMENT).

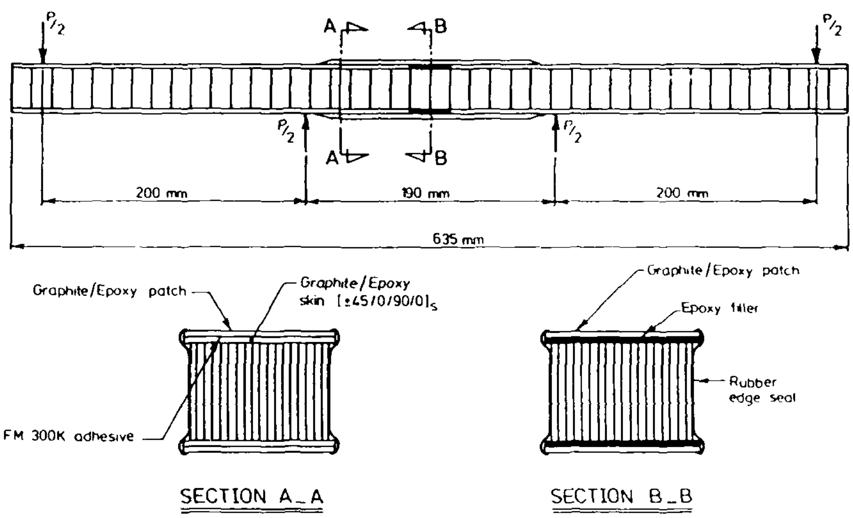



FIGURE 3: SCHEMATIC ILLUSTRATION OF REPAIRED SANDWICH BEAM TEST SPECIMEN SHOWING EPOXY FILLER AND GRAPHITE/EPOXY PATCH.

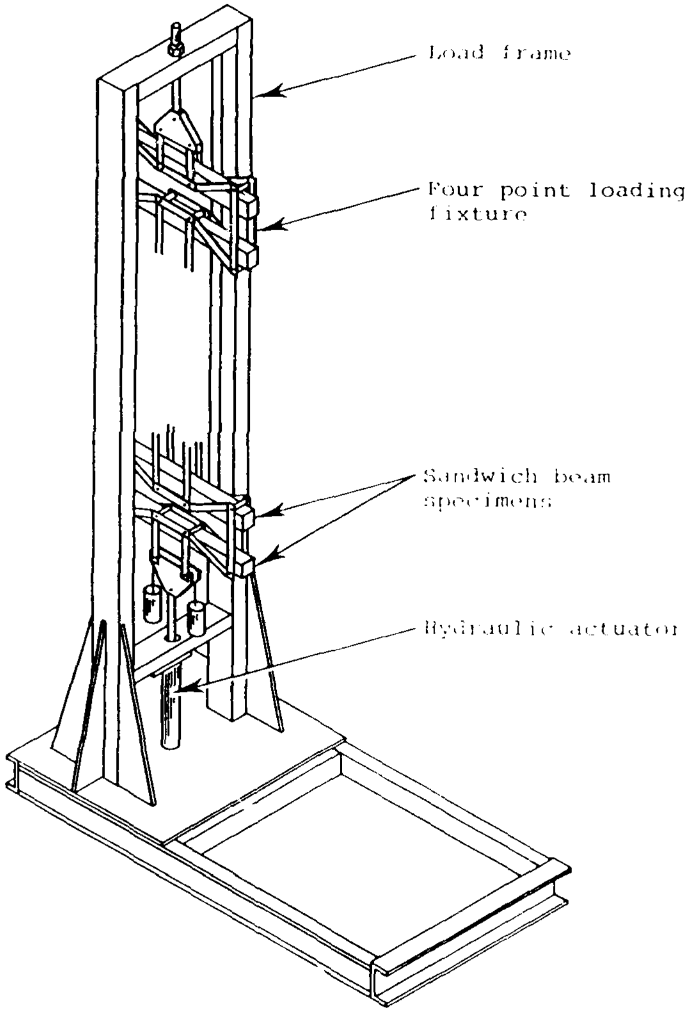



FIGURE 4: SCHEMATIC ILLUSTRATION OF THE LADDER RIG USED TO SUPPLY DYNAMIC POINT LOADING TO CHAINS OF SANDWICH BEAM SPECIMENS.

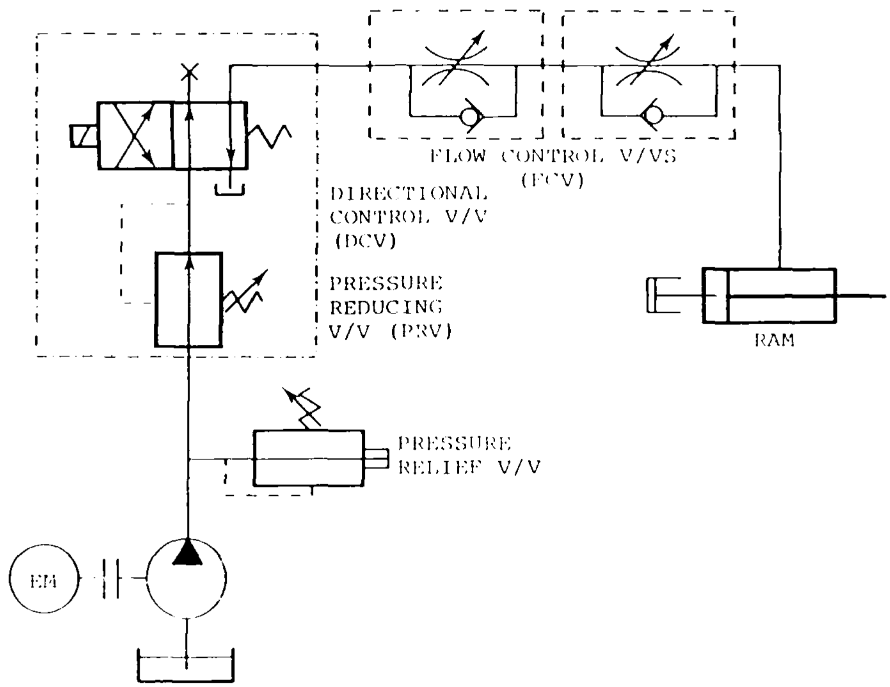



FIGURE 5a: SCHEMATIC DIAGRAM OF THE HYDRAULIC SYSTEM USED IN DYNAMIC LOADING RIGS.

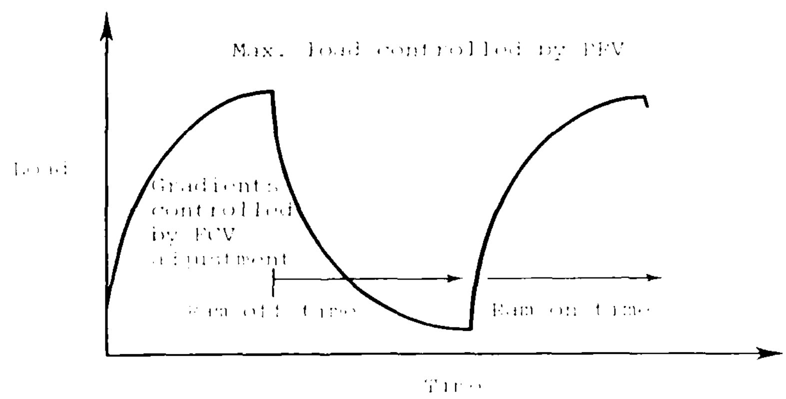



FIGURE 5b: DIAGRAM OF LOADING WAVEFORM ASSOCIATED WITH THE DYNAMIC LOADING RIGS.

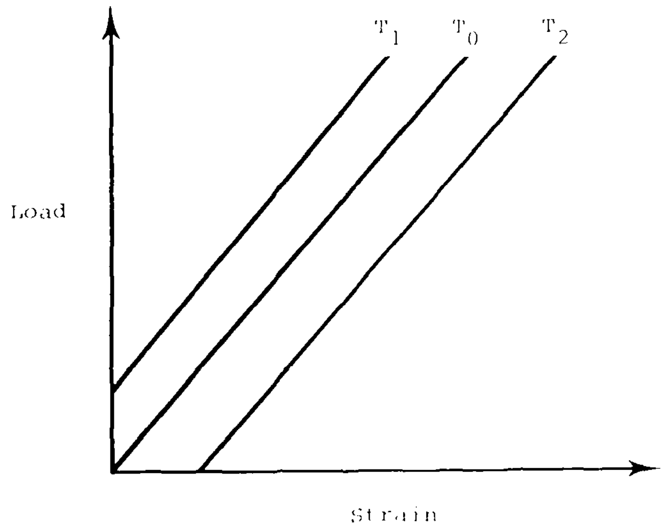



FIGURE 6: THE EFFECT OF TEMPERATURE CHANGES ON BEAM COMPLIANCE

$T_0$ IS THE TEMPERATURE AT WHICH UNLOADED VOLTAGE OFFSET WAS MEASURED (NO THERMAL STRAIN LEFT [illegible]).

$T_1$ IS GREATER THAN OR LESS THAN $T_0$ FOR A SERIES GAGES TO 180°C

$T_1$ IS LESS THAN $T_0$ FOR F SERIES GAGES TO 200°C

$T_2$ IS GREATER THAN $T_1$ FOR F SERIES [illegible] 200°

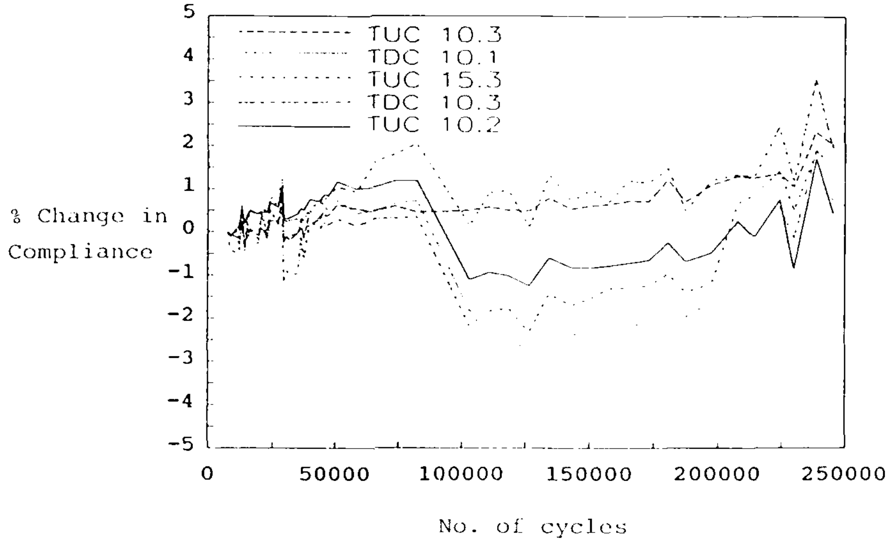



FIGURE 7: RIG 1: COMPLIANCE VERSUS CYCLES.

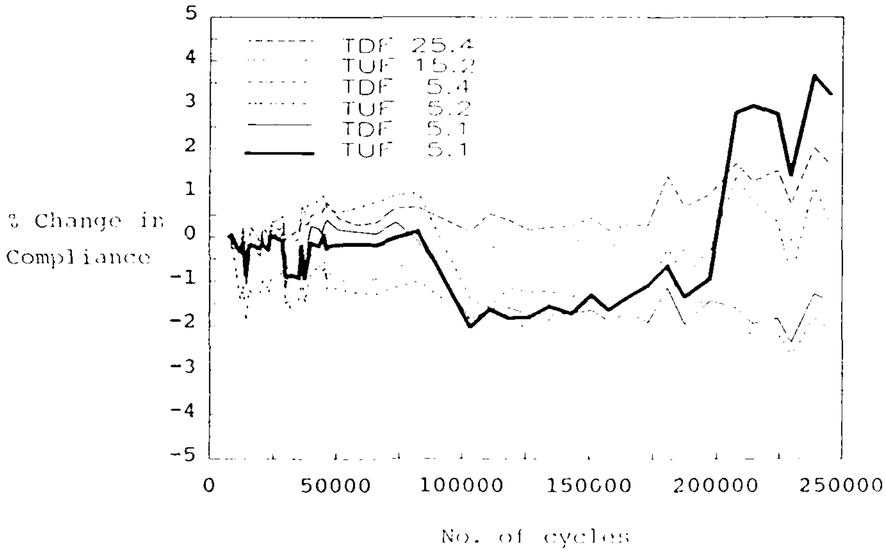



FIGURE 8: RIG 2: COMPLIANCE VERSUS CYCLES.

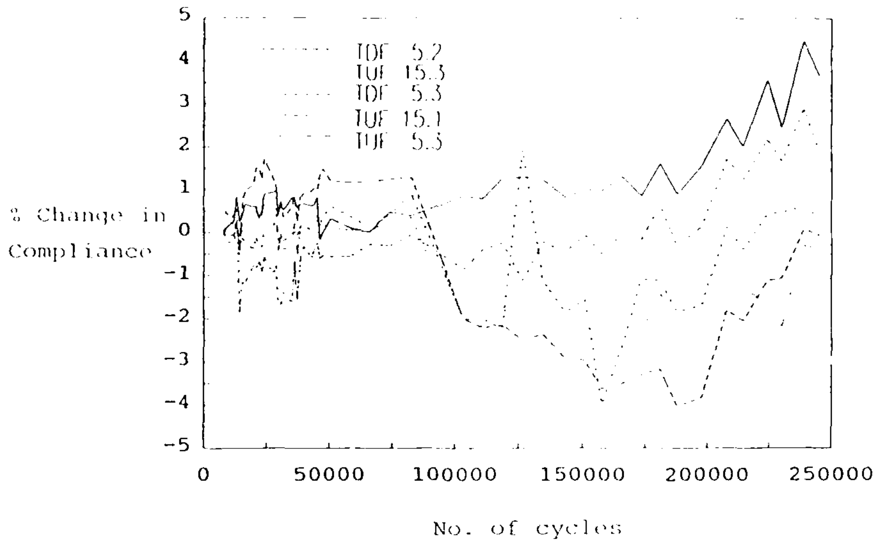



FIGURE 9: RIG 2: COMPLIANCE VERSUS CYCLES.

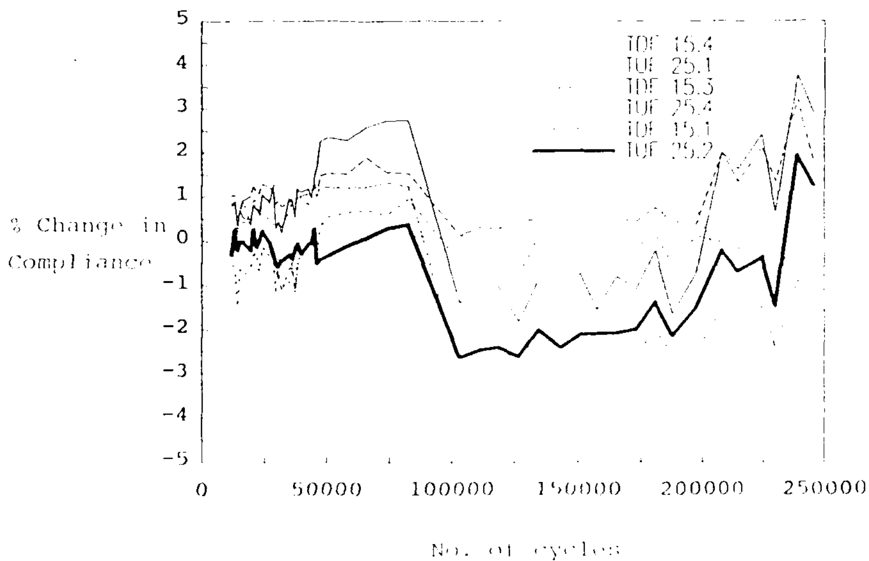



FIGURE 10: RIG 3: COMPLIANCE VERSUS CYCLES.

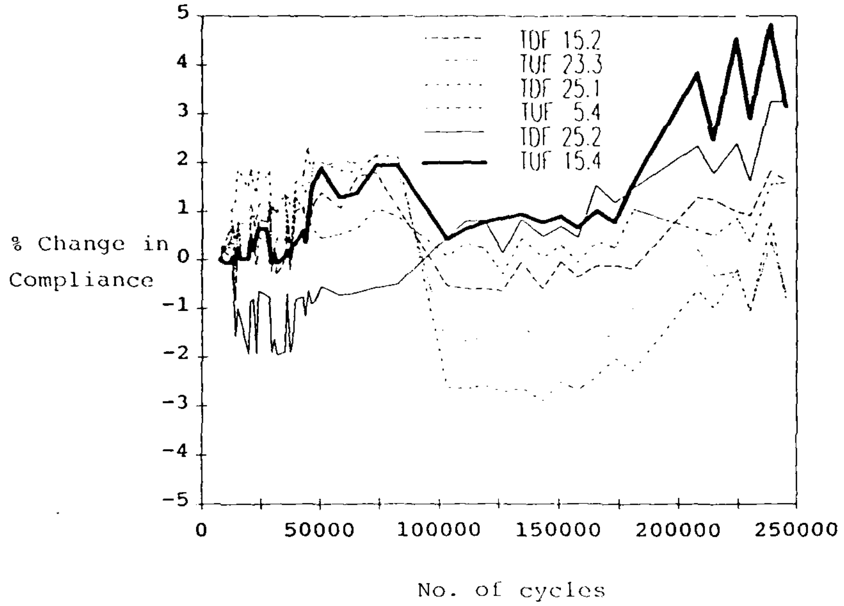



FIGURE 11: RIG 3: COMPLIANCE VERSUS CYCLES.

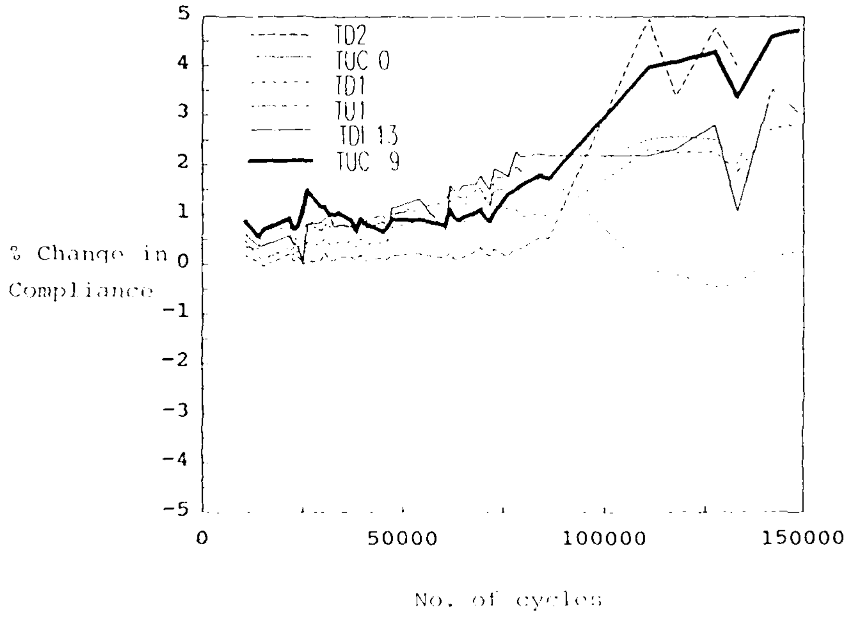



FIGURE 12: RIG 4: COMPLIANCE VERSUS CYCLES.

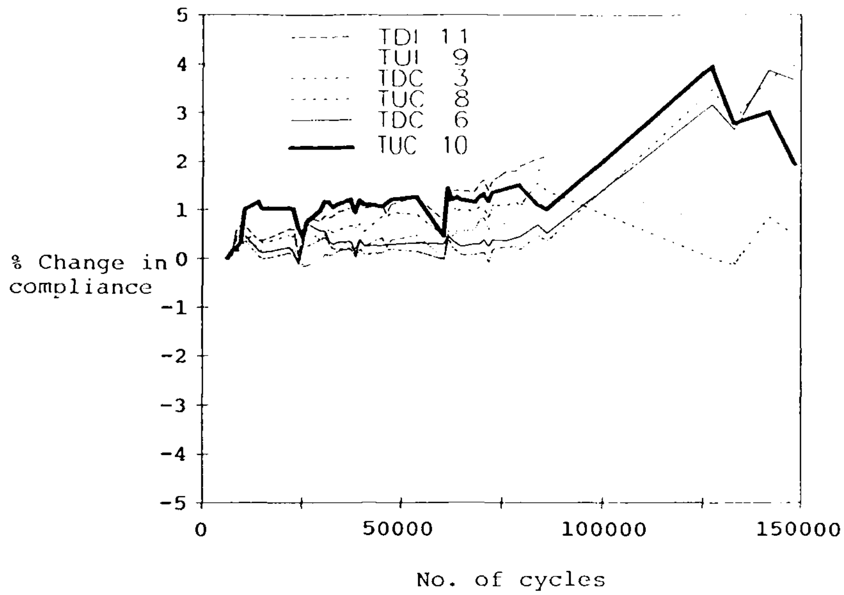



FIGURE 13: RIG 4: COMPLIANCE VERSUS CYCLES.

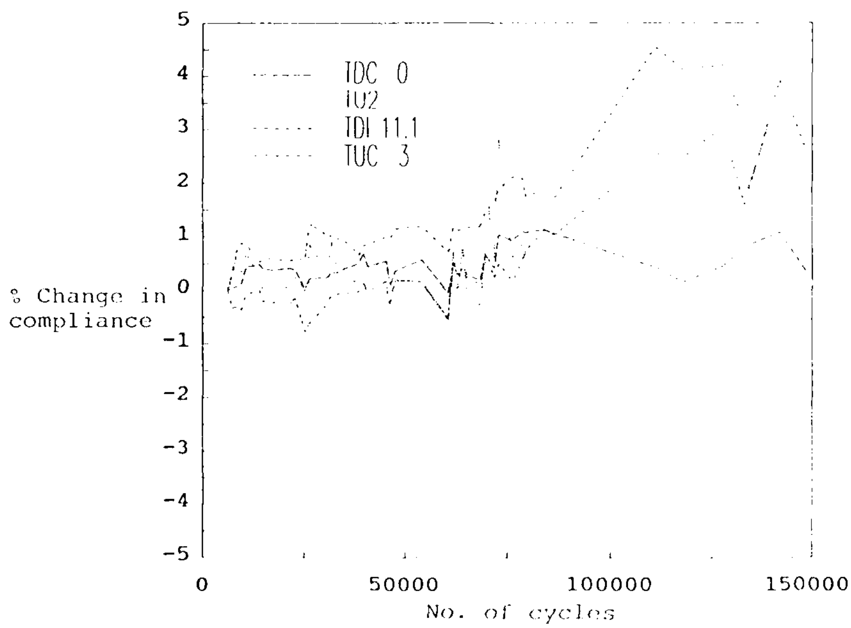
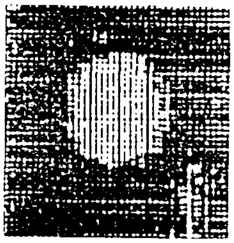



FIGURE 14: RIG 5: COMPLIANCE VERSUS CYCLES.

(a) BEAM TU1 B113, IMPACTED PRIOR TO BONDING THE SKIN TO THE CORE

(b) BEAM TUC B2, IMPACTED AFTER BONDING THE SKIN TO THE CORE



(c) BEAM TUF 153, CONTAINING 15MM DIAMETER TEFLON INCLUSION

FIGURE 15: TYPICAL C-SCANS OF THE DAMAGED HONEYCOMB SANDWICH BEAMS.

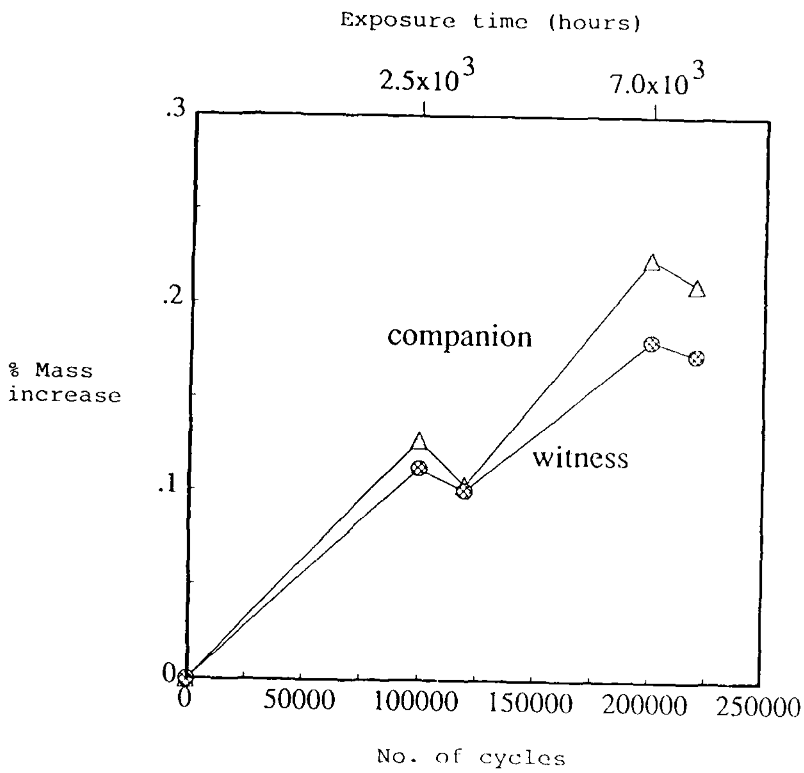



FIGURE 16: WEIGHT CHANGE OF WITNESS AND COMPANION MOISTURE-ABSORPTION COUPONS AGAINST NUMBER OF CYCLES AND EXPOSURE TIME.

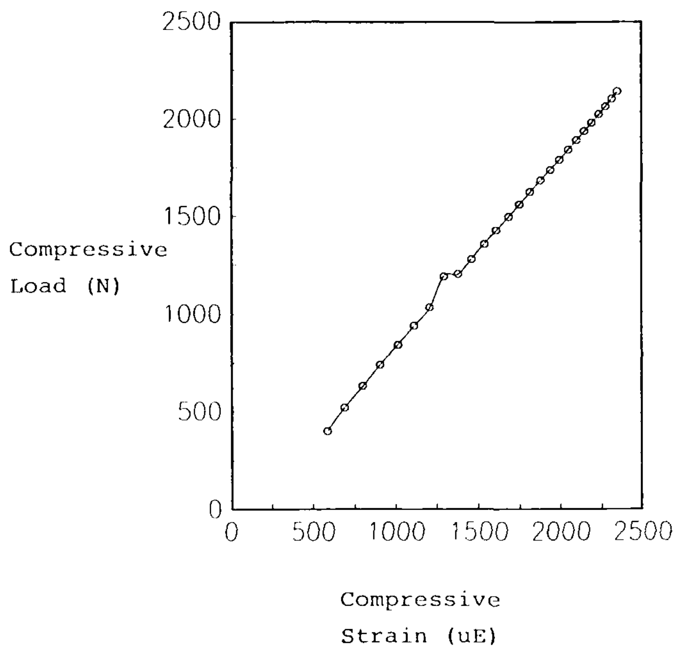



FIGURE 17: TYPICAL LOAD-STRAIN PLOT FOR THE LABORATORY BEAMS

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Durability
Strain Measurement

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0071F

16. ABSTRACT An experimental trial is underway to determine the effect of tropical exposure, cyclic loading and thermal cycling on the long term durability of damaged graphite epoxy laminates. No damage growth has been observed after 300,000 cycles at a strain level of 2500 microstrain.

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